Report as of FY2009 for 2008VT32B: "Treatment Solutions to Reduce Nutrient and Bacterial Inputs to Lake Champlain at Shelburne Farms"

Publications

Project 2008VT32B has resulted in no reported publications as of FY2009.

Report Follows

FINAL REPORT

Treatment Solutions to Reduce Nutrient and Bacterial Inputs to Lake Champlain at Shelburne Farms

PROJECT DATES:
March 1, 2008 - February 28, 2009

PRINCIPAL INVESTIGATORS:
Sarah Taylor Lovell (PI) and Alan McIntosh (co-PI)
Deane Wang & Hisa Kominami

Submitted to:

Vermont Water Resources and Lake Studies Center

for work in cooperation with:

The Agency of Natural Resources, State of Vermont,
The Lintilhac Foundation,
and Shelburne Farms

18 May 2010

EXECUTIVE SUMMARY

Ecological and social functions of Lake Champlain are increasingly threatened by high concentrations of contaminants such as phosphorus which promotes the growth of algae and aquatic plants. Of the 80% of phosphorus entering the lake from non-point sources, approximately 55% is contributed by agricultural activities (Lake Champlain Steering Committee, 2003). Animal waste from agricultural livestock also contributes to harmful strains of bacteria that threaten the health of individuals swimming at public beaches or drinking the water.

Improving the quality of runoff from dairy farms in the Lake Champlain Basin has been challenging and is still a top priority for regional lake management efforts. Long-term studies indicate that lake water quality goals have not been achieved and that doing so will require additional pollution reduction from agricultural sources within the basin. Three studies of water quality were conducted to investigate the relationship between farming practices and runoff entering the lake from Shelburne Farms, a 590-ha pasture-based dairy farm on the shores of Lake Champlain in Vermont.

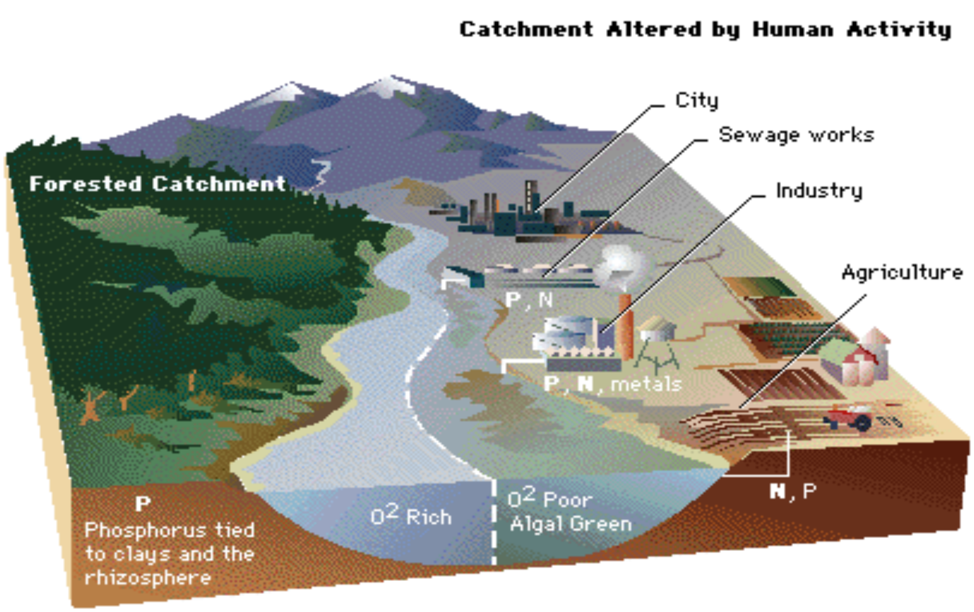
In the first study, agricultural runoff and near-shore lake water quality were monitored through grab sampling during four summers between 2004 and 2008. Monitoring revealed that total phosphorus (TP), dissolved reactive phosphorus (DRP), total suspended solids (TSS), and Escherichia coli concentrations were loosely comparable to concentrations reported for agricultural watersheds in which best management practices (BMPs) had been implemented. However, two lake swimming areas frequently violated Vermont state water quality standards for E. coli after storm events. Results also demonstrated that the two strongest contributors to surface water pollution were the dairy barnyard area and catchment draining to Orchard Cove.

For the second study, the site suitability of three existing composting areas on the farm were evaluated based on a Natural Resource Conservation Service (NRCS) conservation practice standard. The analysis was performed using a geographic information system (GIS) and criteria defined by the NRCS. Results revealed that one composting area is unlikely to pose a threat to water quality. However, the two other composting areas were only partly within suitable areas and may require remedial measures to ensure adequate water quality protection. Additionally, the analysis revealed that one previously used composting area was not properly sited and could potentially have been a source of pollutants to a nearby drainage ditch that discharges into Lake Champlain.

The third study evaluated the start-up performance of the recently built stormwater treatment system at reducing pollutants in agricultural stormwater from the 5-ha dairy barnyard catchment. Between July and December 2009, treatment performance was evaluated by 1) comparing storm flow and non-event flow concentrations of particulate phosphorus (PP), total dissolved phosphorus (TDP), TP, DRP, TSS, and E. coli at the treatment system's inlet and outlet, and 2) quantifying TP and TSS removal efficiencies of a treatment system component (gravel wetland)

during two storms. Results demonstrated that mean storm flow concentrations were significantly lower ($p < 0.05$) at the treatment system's outlet for all measured parameters except E. coli. For one storm in mid-November and another in early December, the gravel wetland retained 39 and 13% of P and 42 and 38% of TSS, respectively.

The results from this study suggest that balancing water quality protection and dairy farming may continue to pose challenges at Shelburne Farms despite long-standing BMPs (e.g., rotational grazing, livestock exclusion, comprehensive nutrient management planning) and recent remedial measures (e.g., stormwater treatment system). However, the results also indicate that adopting additional site-specific BMPs and BMP systems could further reduce agricultural nonpoint source pollution. Indeed, achieving society's water quality goals for Lake Champlain may require more precise P management and more effective measures to control P loss on dairy farms.



INTRODUCTION

The Environmental Protection Agency (EPA) estimates that eutrophication is the most common impairment of surface waters in the US, threatening the supply of clean water used for drinking, recreation, aquatic habitat, and many other functions (US EPA 1996). Eutrophication can be defined as "the process of fertilization that causes high productivity and biomass in an aquatic ecosystem. Eutrophication can be a natural process or it can be a cultural process accelerated by an increase of nutrient loading to a lake by human activity" (EPA/Great Lakes National Program Office). Nutrient enrichment in streams and lakes can result in oxygen depletion, algal blooms, and reduced biodiversity – all of which threaten the overall health and functions of these systems (Carpenter et al. 1998).

Based on an extensive review of the literature, Carpenter et al. (1998) concluded that eutrophication is a widespread problem caused by overenrichment with P and N, in part due to nonpoint pollution from agricultural activities including excess fertilization and manure production. They suggest that a reduction in surplus nutrient flows from agricultural systems and a decrease in agricultural runoff could result in lower levels of nutrients in surface waters, but recovery from the eutrophic state is often a slow process.

As with most large lake systems, water quality in Lake Champlain is largely determined by the quality of surface water runoff from its watershed. Inputs of phosphorus from a variety of nonpoint sources including stormwater (fertilizers, detergents, etc.), agriculture (manure, feed, and fertilizers), and sediment erosion have played a large role in the eutrophication and blooms of toxic algae found in Lake Champlain. In fact, nonpoint sources are estimated to account for 80% of the phosphorus entering the lake, and agriculture contributes up to 55% of this portion (Lake Champlain Basin Steering Committee, 2003). As a result of the decline in water quality, millions of dollars have been spent on the development and implementation of Lake Champlain total maximum daily loads (TMDL's) to reduce P inputs from the watershed. Pathogens including bacteria, viruses, and parasites are another cause for concern regarding the quality of the water in Lake Champlain. If ingested while swimming or drinking contaminated water, these organisms can result in gastrointestinal illnesses that threaten the health of the public. Livestock manure is known to be a source of these pathogens, so agricultural management including grazing, manure storage facilities, and manure applications as fertilizer play a critical role in water quality (Fajardo et al 2001).

Shelburne Farms, a 1400-acre working farm with 250-270 cows including young stock, milking cows, and beef cows, strives to demonstrate sustainable farming practices. The farm represents interests of many farms in the Lake Champlain watershed with a focus on sustainable local food production, agri-tourism, and environmental stewardship. The issue of water quality, however, is particularly critical as Shelburne Farms is located directly on Lake Champlain. The implementation of best management practices including a grass-based system, large land base for manure spreading, and comprehensive Nutrient Management Plan, would suggest that Shelburne Farms has low potential for nutrient runoff and bacterial contamination from agricultural activities.

The purpose of these studies was to 1) characterize the scope of the nonpoint source pollution problem at Shelburne Farms through a summer sampling program employing grab samples, 2) provide an analysis of site suitability for composting operations, and 3) evaluate the initial efficacy of a stormwater treatment system for the 5-ha dairy barnyard catchment area.

METHODS

Each of the studies required different methods, described below.

<u>Agricultural runoff and near-shore lake water quality</u>

To assess the quality of agricultural runoff into Lake Champlain from Shelburne Farms, grab samples were collected at various locations on the farm during four summers between 2004 and 2008. Over these four summers, twenty-one storm flow and four baseflow samples were collected at various sites on the farm.

Collected samples were transported on ice to the Agricultural and Environmental Testing Laboratory at the University of Vermont and stored at 4°C until further processed. Within 24 h, TDP and DRP samples were filtered using pre-washed 45-μm membrane filters and were either stored at -20°C until analyzed or analyzed immediately. DRP concentrations were determined colorimetrically using the stannous chloride method (Eaton et al., 1998). TP samples were either stored at -20°C until analyzed or were stored for less than a month at 4°C until analyzed. TP and TDP concentrations were determinedcolorimetrically using the stannous chloride method following digestion with persulfate (Eaton et al., 1998). PP was determined by subtracting TDP values from TP values. TSS was measured by weighing the dried residue on a glass-fiber filter disk following filtration and drying at 103° to 105°C (Eaton et al., 1998). All *E.coli* samples were analyzed within 24 h of collection using the Quanti-Tray ® method (Eaton et al., 1998).

<u>Site suitability of three existing composting areas</u>

Site suitability was modeled using GIS algorithms from several developed data layers. High resolution Chittenden County LIDAR data was converted and interpolated (krigging algorithm in Geo-Analyst) into a Digital Terrain Model (DTM) for all of Shelburne Farms. The DTM was used to generate hill shade and slope layers. The shoreline and residences were digitized from orthophotos from the Chittenden County Metropolitan Planning Organization (CCMPO) to define areas unsuitable for siting compost piles. Based on the NRCS selection criteria, a 500' buffer was created for the residence layer and a 300' buffer was created for the shoreline layer. Using the streams layer from a GIS geodatabase obtained for Shelburne Farms, a 100' buffer was created for existing streams. The soils layer used in this analysis was obtained from the USDA-NRCS soil survey data available through the Vermont Center for Geographic Information (VCGI). Layers for seasonal high water table and slopes less than eight percent were also created. The land use/land cover layer from the Shelburne Farms geodatabase was used to find either hayfields or open land. The site suitability analysis map was developed from these data layers and the Vermont NRCS criteria for siting composting areas (NRCS, 2009).

Start-up performance of the stormwater treatment system

Rainfall was measured using a RG3-M HOBO Data Logging Rain Gauge (Onset Computer Corporation, Pocasset, MA). Temperature was measured at 30-minute intervals using the same data logger used for measuring rainfall, which was housed in a RS1 Solar Radiation Shield (Onset Computer Corporation, Pocasset, MA).

Grab samples were collected during storm flows and non-event flows at the entry and exit points of the stormwater treatment system. Storm flows were sampled at least once per storm event, but multiple samples were often collected so that data were representative of different stages of flow through the treatment system. When multiple samples were collected, results were averaged to provide a storm average for each measured parameter. During non-event flows, there was usually very low flow into the inlet pond and gravel wetland, but never flow through the entire system. Non-event samples were usually collected weekly, though gravel wetland maintenance and storm flows sometimes prevented sample collection.

Gravel wetland inflows were measured in the inlet water level control structure using a sharp-crested 30° V-notch weir and a 6712 automatic sampler with an Isco 750 Area Velocity Flow Module (Teledyne Isco, Inc., Lincoln, NE). The flow module was placed in a stilling well and recorded the height of water passing through the V-notch weir at 2- minute intervals. During stormflows, a water level rise of 2.5 cm above the lowest point in the V-notch weir triggered the automatic sampler to collect up to 24 discrete 1000 ml samples.

Gravel wetland outflows were measured in the outlet water level control structure using a 6712 automatic sampler with an Isco 720 Submerged Probe Flow Module (Teledyne Isco, Inc., Lincoln, NE). The flow module was placed in a stilling well and recorded water level at 2-minute intervals. Water levels were then converted to flow rates using Manning's equation for a smooth PVC pipe with a 99-mm interior diameter and a slope of 0.03. A higher Manning's roughness coefficient (0.037) than what is typically used for smooth PVC (0.011 to 0.017) was used because it resulted in predicted flow rates that best approximated empirical flow rates measured on two separate occasions.

Flow rates were determined empirically during the falling limb of two storm flows by recording the time it took to fill a specified volume in the cylindrical outlet water level control structure and dividing the volume by the corresponding time. Flow rate was measured four times during each storm flow, averaged, and then compared to predicted flow rates using a range of different roughness coefficients. During storm flows, a water level rise of 1.5 cm above the bottom lip of the outflow pipe triggered sampling to begin.

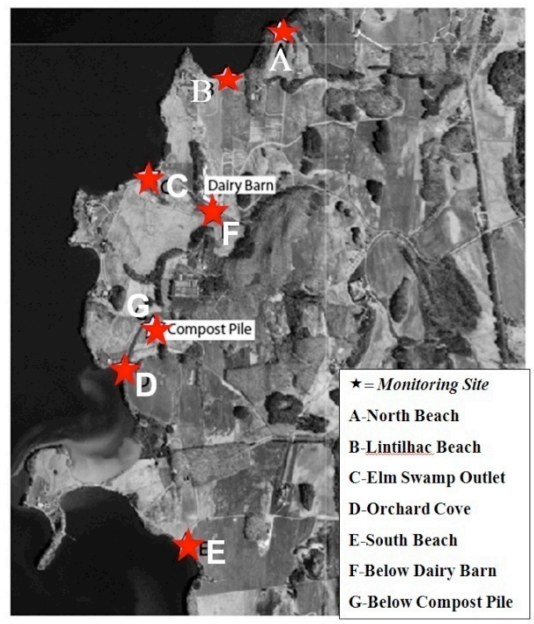
Water quality analyses followed the procedures used for grab sample analyses. All statistical tests for phosphorus, TSS, and *E. coli* were performed using JMP software version 8.0.1 (SAS

Institute, 2009) at an α of 0.05. Paired *t* tests were performed for parameters meeting the assumption of normality, while Wilcoxon signed-rank tests were performed when the distribution of differences were non-normal. Boxplots were created in STATA version 11 (StataCorp, 2009). Boxplot outliers were defined according to Tukey.

RESULTS

<u>Agricultural runoff and near-shore lake water quality</u>

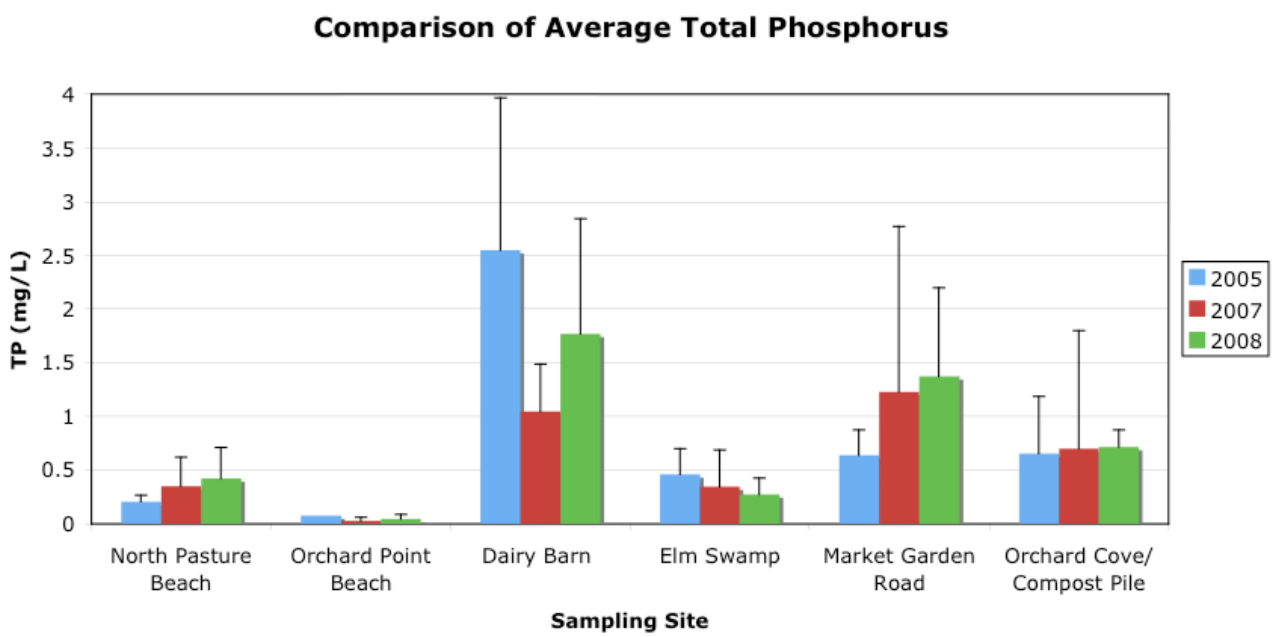
Monitoring Sites

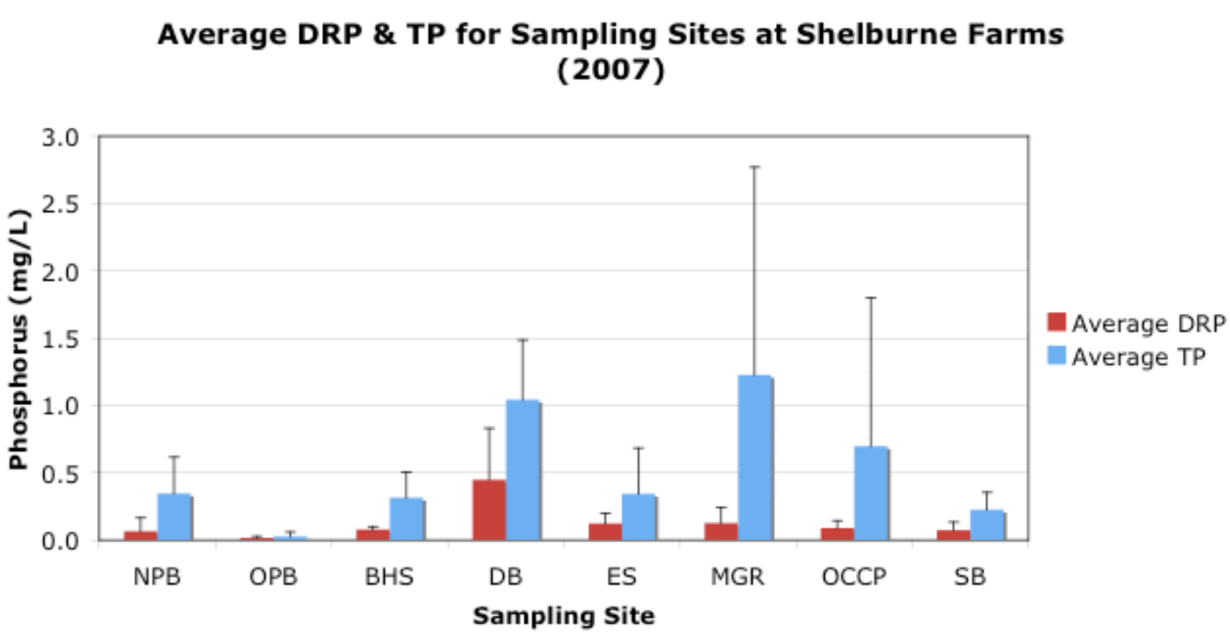


Over four summers, twenty-one storm flow and four baseflow samples were collected at various sites on the farm. Storm event rainfall amounts ranged from as little as 0.5 cm to as high as 5.2 cm. For all summers, precipitation during the month of July was higher than thirty-year precipitation averages for the area.

Stormflow median TP concentrations at outfall sites were from 0.3 to 0.6 mg L^{-1}. These results were comparable to values reported for similar studies in the Northeast. Bishop et al. (2003), for instance, reported annual flow-weighted mean TP concentrations from 0.276 to 0.363 mg L^{-1} for storm event monitoring in a small dairy farm watershed in the Catskills region of New York. The 160-ha dairy farm in the study implemented numerous BMPs and showed modest water quality improvements over four years of extensive monitoring (Bishop et al., 2003). A similar study conducted in a 38-ha dairy farm watershed reported outlet TP concentrations as high as 0.648 mg L^{-1} during storm events despite whole farm planning and the implementation of numerous BMPs (Noll and Magee, 2009). McDowell et al. (2001) also reported a mean TP concentration of 0.4 mg L^{-1} and a concentration range from 0.024 to 1.318 mg L^{-1} for stormflows for a 39.5-ha agricultural watershed in the Chesapeake Bay Basin.

TP concentrations were frequently below 1.0 mg L^{-1}, but high concentrations were observed at individual sites - OCCP on June 4, 2007, at SBN on July 22, 2005 and August 1, 2005. TP was also high at ES on July 22, 2005, but only compared to other sampling dates at that site. It is difficult to know why TP concentrations were high at OCCP, SBN, and ES on those particular dates, since TP concentrations in surface runoff can vary significantly at a sampling location both during and between storm events. High TSS concentrations were also observed at OCCP, SBN, and ES on those dates, which suggest that higher amounts of particulate phosphorus were likely present in surface runoff.


Comparison of Average Total Phosphorus
TP (mg/L)
0
0.5
1
1.5
2
2.5
3
3.5
4
2005
2007
2008
North Pasture Beach
Orchard Point Beach
Dairy Barn
Elm Swamp
Market Garden Road
Orchard Cove/ Compost Pile
Sampling Site


Average DRP & TP for Sampling Sites at Shelburne Farms (2007)
Phosphorus (mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Average DRP
Average TP
NPB
OPB
BHS
DB
ES
MGR
OCCP
SB
Sampling Site

Baseflows were sampled only twice for TP, but the concentration range for outfall sites (0 to 0.4 mg L^{-1}) was also comparable to ranges reported in the scientific literature. Medalie (2007) and McDowell et al. (2001), for instance, reported ranges from 0.018 to 0.233 mg L^{-1} and 0.003 to 0.252 mg L^{-1}, respectively. Additionally, Budd and Meals(1998) reported an inter-quartile range from 0.1 to 0.3 mg L^{-1} for agricultural streams based on an extensive review of the literature. Bishop et al. (2003) reported 0.06 mg L^{-1} as the average annual flow-weighted mean TP concentration for baseflows from four years of post BMP monitoring.

Storm flow median DRP concentrations at outfall sites were from 0.05 to 0.12 mg L^{-1}, while the total range was from 0.01 to 0.29 mg L^{-1} . Like TP, DRP concentrations were also comparable to similar studies conducted in agricultural watersheds. McDowell et al. (2001) reported a mean DRP concentration of 0.128 mg L^{-1} and a total range from 0.005 to 1.090 mg L^{-1}.
Figure @ shows the percent TP as DRP at outfall sites during stormflows. The results suggest that particulate phosphorus losses are generally higher at NPB and OCCP than at the other outfall sampling sites.

Taken together, the results demonstrate that phosphorus concentrations at outfalls were consistent with values reported for similar agricultural watersheds where BMPs have been effective at reducing phosphorus loading to downstream water bodies.

TP concentrations at stream/drainage ditch sites tended to vary more and were frequently higher than at other sampling locations on the farm. Stream/drainage ditch concentrations ranged from low (0.07 mg L^{-1}) to high (4.4 mg L^{-1}). Lower TP concentrations were occasionally observed at BHS, DB, and MGR, but never at DBM, indicating that the dairy barnyard acts as a significant pollutant source during summer storms. Not surprisingly, the highest median values were from the DB (1.5 mg L^{-1}) and DBM (2.0 mg L^{-1}), sampling sites located directly downstream from the dairy barnyard area. Though barnyards are generally small in spatial extent, they can contribute to significant summertime P loading, especially if linked to hydrologically active areas (Hively et al., 2005). High TP concentrations were also observed at MGR, which suggests that there may be an upstream pollutant source. The greater variability and high concentrations observed at DB and MGR might be caused by sediment-laden surface runoff from nearby dirt roads. On several occasions during field sampling, sediment- laden runoff was observed flowing into drainage ditches upstream from the two sampled locations.

TP concentrations were lowest at BHS (0.1 to 1.6 mg L^{-1}), a sampling site below intensively grazed upland pastures, but these concentrations were somewhat higher compared to values reported by others (Bishop et al., 2003; Noll and Magee, 2009). Field observations suggest that remedial measures in upstream areas could improve water quality observed at BHS. Since much of the TP at BHS is likely particulate phosphorus, reducing sediment inputs into the stream from roadside drainage ditches and stream crossings could help to reduce phosphorus loading. In addition, reducing cow traffic near the headwater of the stream reach is also likely to improve downstream water quality. Indeed, numerous studies indicate thatthe most effective non-point source BMPs dissociate pollutant source areas from areas prone to generating runoff (Easton et al., 2008). Currently, cows congregate very close to the stream headwater because of a gate that connects two pastures in that location. As a result, cows deposit manure close to the stream and expose soils from heavy traffic, which can both lead to increased phosphorus losses. Stream channel and bank erosion may also contribute to high particulate phosphorus losses at BHS, and may be representative of natural processes within the stream reach.

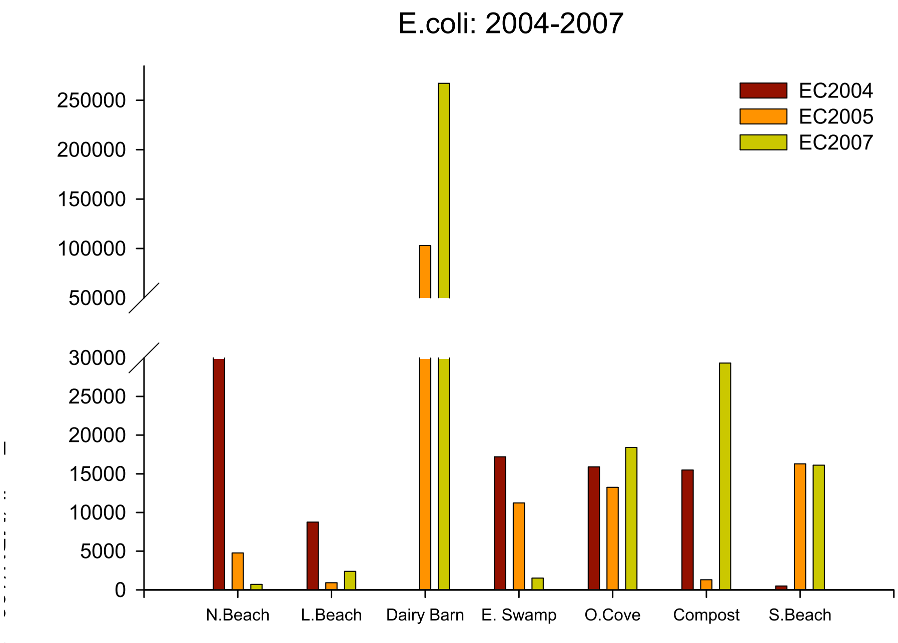
The frequently high TP concentrations observed at DB, DBM, and MGR suggest the presence of upstream pollutant sources, however, concentrations observed at stream/drainage ditch sites were also much lower than values reported in other studies. Very high TP concentrations (13 to 18 mg L^{-1}) have been reported in surface runoff from cow paths, barnyards, and barnyard filter strips (Hively et al., 2005; Schellinger and Clausen, 1992). Nevertheless, extremely high TP concentrations were never observed at Shelburne Farms despite sampling downstream from likely pollutant sources.

Lake sampling revealed that TP and DRP concentrations at wading depth were frequently lower compared to outfall concentrations. At ES_L, TP concentrations were between two-fold and fourteen-fold lower than at ES for eight of the ten sampled events and ranged from 0.01 to 0.3 mg L^{-1}. DRP concentrations were nearly two-fold to five- fold lower at ES_L for all sampling events and ranged from 0.01 to 0.09 mg L^{-1}. Concentrations at OPB_L were similar to ES_L and ranged from 0 to 0.3 mg L^{-1} for TP and from 0 to 0.05 mg L^{-1} for DRP. Both TP and DRP concentrations were generally lower at OPB_L. For nearly all dates, in-lake TP concentrations were higher than the main lake phosphorus criterion (0.010 mg L^{-1}) and frequently were as high or higher than TP concentrations reported for eutrophic parts of the lake. The results suggest that storm flow discharges frequently affected near-shore lake phosphorus concentrations at Shelburne Farms.

During summer storms, *E. coli* concentrations at lake sites ranged from 5 to 12,993 MPN/100 ml OPB_L and from 31 to 15,900 MPN/100 ml at ES_L. Median concentrations at OPB_L and ES_L were 116 and 649 MPN/100 ml, respectively. The results indicated that *E. coli* concentrations exceeded Vermont's 77 MPN/100 ml beach bathing standard 75% of the time at OPB_L and 82% of the time at ES_L. This suggests that swimming near outfalls during or shortly after storm events probably poses risks to human health.

Average *E. coli* concentrations (MPN/100 ml) at swimming areas in 2008.

	Monitored Swimming Areas	
Sampling Date	**Orchard Point Beach**	**Elm Swamp Lake**
7/3/08	133	649
7/9/08	44	285
7/13/08	5	62
7/18/08	80	435
7/20/08	>2419	2419
7/24/08	10462	9208
8/2/08	93	1986



Average *E. coli* concentrations (MPN/100 ml) at sampling sites in 2007. Highlighted rows indicate days where background flows were sampled.

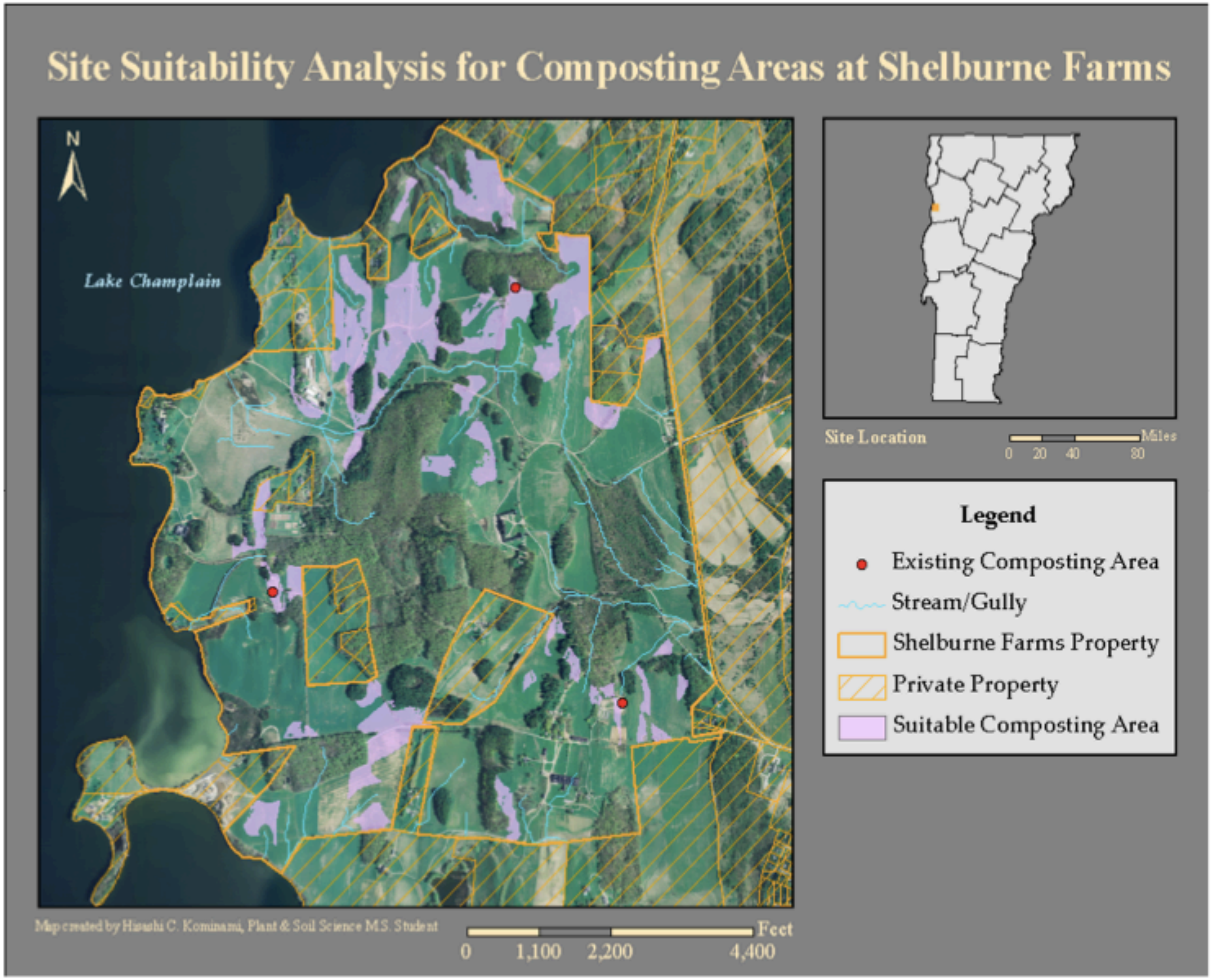
	Monitored Outflows & Drainages						
Sampling Date	**NPB**	**BHS**	**DB**	**ES**	**MGR**	**OCCP**	**SB***
5/29/07	80	NA	421	NA	17	793	1
6/4/07	225	NA	117,430	113	84,595	2,076	2
6/19/07	1,476	2,500	629,250	2,419	84,595	141	44
7/6/07	NA	NA	4,100	NA	NA	NA	NA
7/9/07-(1)	124	3,915	980,400	2,419	7,875	2,076	1,176
7/9/07-(2)	NA	NA	NA	NA	NA	2,419	2,419
7/13/07	2,419	29,500	93,000	1,410	2,000	410	4,310
7/19/07	413	26,450	311,800	1,220	26,050	139,230	121,008
8/9/07	170	1,110	1,000	NA	100	6	2

With some exceptions, the results of this study suggest that current BMPs at Shelburne Farms are as effective at reducing pollutant concentrations in agricultural runoff as in similar agricultural watersheds in the Northeast. Outfall concentrations of TP, DRP, TSS, and *E. coli* were comparable to concentrations reported for extensively monitored agricultural watersheds with BMPs. However, TP, TSS, and *E. coli* concentrations werefrequently high at sampling sites in the OCCP watershed, which suggests that agricultural activities within the watershed are degrading downstream water quality. Field observations provided support for our hypothesis that the composting area within the OCCP watershed may be a significant source of agricultural pollution. Other upstream areas within the watershed including the cultivated field, farm roads, and drainage ditch channel may also contribute to high pollutant concentrations observed in surface runoff. Unusually high TP concentrations observed at some outfall sites were coincident with high TSS concentrations suggesting that soil erosion is an important pathway for P losses from the landscape.

Lake sampling demonstrated that swimming near stormwater outfalls during or shortly after storm events is very likely a risk to human health. However, additional data provided by Shelburne Farms suggests that the risk to human health from waterborne pathogens may be short-lived. Specifically, *E. coli* samples collected one day after rainfall events never exceeded the Vermont bacteriological water quality standard at swimming areas. Nevertheless, further research is needed to determine the extent of fecal contamination in near-shore areas of the lake as a result of stormwater discharges. Though current BMPs appear to be generally effective for phosphorus and suspended sediments, achieving Vermont water quality standards for the lake may require additional and more site-specific BMPs.

Site suitability of three existing composting areas

Below is the map output of suitable areas identified through our analysis and the locations of existing composting areas at Shelburne Farms. The site suitability analysis indicates that only the northernmost composting site at Shelburne Farms is located completely within a suitable area and is not likely to pose risks to air and water quality. Since the composting site is nearly surrounded by woodlands and bordered by suitable pastures to the south, it suggests that odor, runoff, and leaching from the site are not likely a problem. The soils at the site are classified as a Stockbridge stony loam and therefore should provide good drainage. Runoff and leachate from the site are likely to infiltrate at the site and in pastures to the south.



Site Suitability Analysis for Composting Areas at Shelburne Farms
N
Lake Champlain
Site Location
0
20
40
80
Miles
Legend
Existing Composting Area
Stream/Gully
Shelburne Farms Property
Private Property
Suitable Composting Area
Map created by Hisashi C. Kominami, Plant & Soil Science M.S. Student
0
1,100
2,200
4,400
Feet

The easternmost composting site is located in areas identified in the analysis as being both suitable and unsuitable. Closer inspection of the unsuitable areas revealed that the eastern part of the site and areas west were excluded because of steep slopes and that the northern part of the site was excluded because of a gully less than 100 ft away. Though these results suggest that runoff and leaching from the site could pose water quality problems, observations during site visits seemed to suggest that the site could be used for composting, perhaps with some modifications, without adversely impacting water quality. There appeared to be sufficient flat areas for the composting operation and the areas east and west of the composting site could provide adequate infiltration for runoff and leachate. It is also possible that the gully may not act as significant transport pathway for pollutants from the site.

According to the NRCS, sites that do not meet allthe criteria can still be used for composting areas if modifying the site adequately protects against surface and ground water pollution. Runoff diversion ditches, earthen berms, and windrow covers are a few examples of site modifications that could be used to keep runoff and leachate within the composting area. Soils at the site and in the vicinity are all Palatine silt loams, which are likely to provide good drainage and allow for proper compost management. Our analysis results at this particular site point to some of the limitations of using coarse resolution GIS data and indicate that on the ground fact checking can be very useful. Fact checking at this site revealed the site could potentially be used for siting a composting area, even though our analysis results indicated the opposite. Nevertheless, for this particular composting site, consulting with a qualified soil scientist or agricultural engineer would help to determine more conclusively whether the site could be used without compromising water quality.

Our analysis also revealed that there are numerous other parcels of varying size on the farm that could serve as temporary storage areas for dairy manure. However, because our analysis represents a starting point for locating composting areas, other criteria may also need to be considered to determine whether sites are actually suitable. In Shelburne Farms' case, protecting the visual quality of the landscape and minimizing odor problems may limit the number of available sites that could be used. Prevailing winds on the property could also restrict the use of certain areas if winds at a site carry odors to neighboring properties or to areas frequented by visitors. Access to composting sites and a nearby water source are also important since farm equipment and water are both necessary for properly managing composts. It is also preferable to site composting areas close to where finished composts will be used. The suitable areas identified in this analysis that abut private property lines may also not be suitable if landowners are not willing to allow those sites to be used.

Start-up performance of the stormwater treatment system

Results from inlet and outlet grab sampling of the stormwater treatment system and intensive sampling of the gravel wetland indicate that, for most storms, the system effectively reduced pollutants in agricultural runoff from the barnyard area between early July 2009 and early December 2009.

1. Inlet and Outlet Grab Sampling

Between 10 July and 10 December 2009, twelve storm flows were sampled, representing approximately half of all runoff-producing storm events during the study period. Storm event characteristics such as rainfall amount, precipitation intensity, and duration varied considerably for the sampled storm flows.

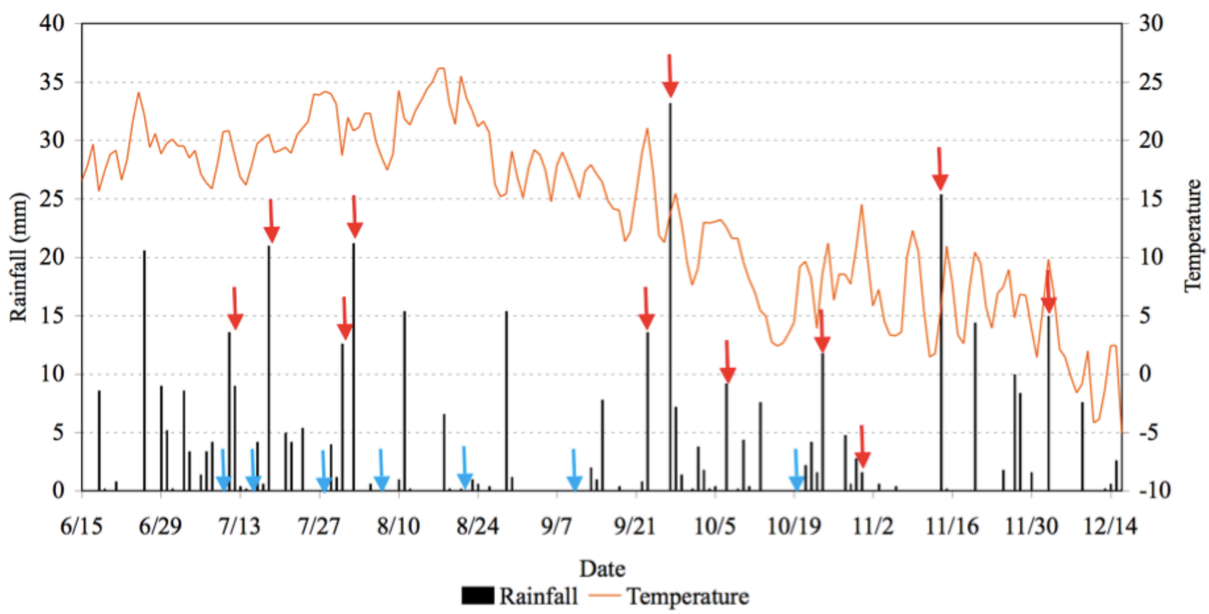


Figure 4.3. Sampling dates, daily rainfall, and average temperature at the stormwater treatment system during the study period, July 10, 2009 to December 10, 2009. Red arrows indicate storm flow sampling and blue arrows indicate non-event flow sampling

Of the twelve storm flows sampled, half were grab sampled either two or three times, and two were intensively sampled with automatic samplers. Because multiple grab samples were often collected during each storm flow, samples from the study were representative of various stages of flow through the treatment system including the rising limb, peak, and falling limb of storm flows. Overflow from the inlet pond to the outlet pond was observed for three different storm flows and could also have occurred on three other dates. The storm event from 27 September through 28 September 2009 had the highest rainfall amount of any of the storms during the study period, is likely to have resulted in overflow, and produced a bimodal runoff response.

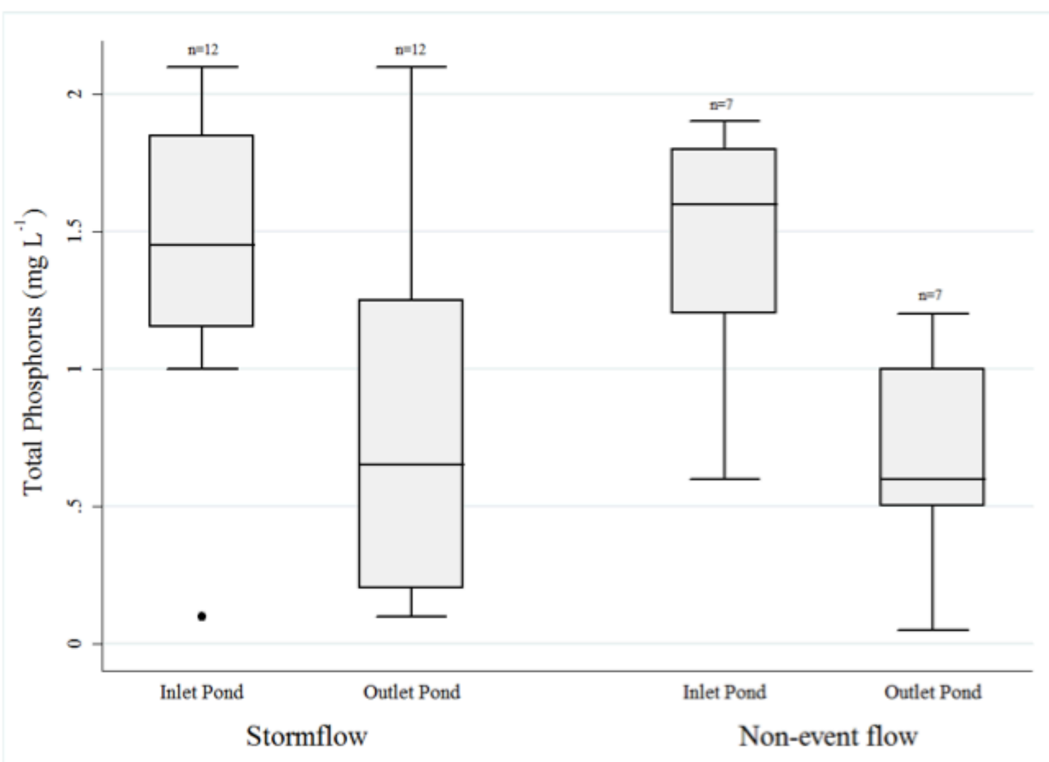
Sampling		[TP]		[PP]		[TDP]		[DRP]		[TSS]		[*E. coli*]		
Date	**Time**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Description of Flow**
7/11	7:40 PM	1.8	0.7	1.1	0.4	0.8	0.3	0.7	0.3	36	30	4,400	100	Flow into gravel wetland
7/12	9:13 AM	2.1	1.7	1.1	1.0	1.0	0.8	1.1	0.8	113	81	236,000	242,000	Near peak flow through system, overflow may have occurred
7/12	5:40 PM	2.0	1.9	0.8	0.9	1.3	1.0	1.3	1.1	73	62	61,000	173,000	Fow through system
7/18	11:08 AM	1.8	2.1	0.7	0.3	1.1	1.8	1.0	1.2	36	56	24,000	613,000	Flow through system, overflow may have occurred
7/31	9:44 AM	1.1	0.6	0.3	0.2	0.8	0.4	0.7	0.2	26	10	1,300	100	Flow into gravel wetland
7/31	4:52 PM	1.4	0.6	0.5	0.2	0.9	0.4	0.7	0.2	19	12	4,100	200	Flow into gravel wetland just before flow into outlet pond
7/31	7:25 PM	1.3	0.6	0.4	0.1	0.8	0.5	0.6	0.2	24	9	7,700	200	Flow through system
8/2	7:24 PM	1.8	1.8	1.1	1.0	0.8	0.8	0.8	0.7	90	132	461,000	613,000	Flow through system, overflow observed
8/3	7:55 PM	2.3	2.1	1.0	1.2	1.3	1.0	1.3	1.0	126	102	1,410,000	345,000	Flow through system
8/11	8:20 PM	1.3	0.9	0.4	0.1	0.9	0.7	0.7	0.6	34	21	14,100	5,200	Flow into gravel wetland
8/12	8:00 AM	1.5	0.8	0.5	0.2	1.0	0.6	0.9	0.6	39	13	249,000	2,900	Flow into gravel wetland just before flow into outlet pond
9/23	6:11 PM	0.2	0.1	0.1	0.1	0.0	0.0	0.1	0.0	14	24	800	5,200	Flow into gravel wetland
9/28	10:09 PM	1.1	0.2	0.1	0.1	1.0	0.1	1.1	0.2	44	26	58,000	20,000	Flow through system, overflow probably occurred
9/29	9:54 AM	1.0	0.2	0.1	0.1	0.9	0.1	1.0	0.2	40	24	20,000	17,000	Lower flow through system than at previous sampling
9/29	4:25 PM	1.1	0.3	0.3	0.2	0.9	0.1	1.0	0.2	32	20	13,000	12,000	Lower flow through system than at previous sampling
10/7	9:06 AM	1.2	0.2	0.8	0.2	0.4	0.0	0.5	0.0	27	25	1,000	100	Low flow into gravel wetland
10/25	6:52 PM	1.0	0.3	0.4	0.2	0.6	0.0	0.8	0.1	36	14	13,000	1,000	Flow through system
10/31	5:20 PM	1.5	0.2	1.0	0.2	0.6	0.0	0.8	0.2	30	13	3,300	200	Flow into outlet pond
11/14	6:45 PM	1.7	0.4	-	-	-	-	-	-	159	30	-	-	Flow into outlet pond
11/14	10:30 PM	1.8	1.1	-	-	-	-	-	-	76	48	-	-	Peak flow through system, overflow observed
11/15	7:00 AM	1.9	0.6	-	-	-	-	-	-	42	33	-	-	Flow through system
12/3	9:29 PM	1.9	1.1	-	-	-	-	-	-	87	55	36,000	16,000	Flow through system, overflow observed at 12:40 PM on 12/3/09
Max		2.1	2.1	1.0	1.1	1.1	1.8	1.1	1.2	108	117	937,000	613,000	
Median		1.5	0.7	0.6	0.2	0.9	0.3	0.8	0.2	36	25	24,000	5,200	
Mean		1.4	0.8	0.6	0.3	0.7	0.5	0.8	0.4	50	37	116,600	115,700	
Min		0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	14	10	800	100	
St. Dev.		0.6	0.7	0.3	0.3	0.3	0.6	0.3	0.4	31	31	276,000	219,000	
C.V.		0.39	0.87	0.54	1.08	0.46	1.27	0.39	1.07	0.62	0.82	2.37	1.89	
Median Reduction (%)		55		67		71		75		32		78		
Mean Reduction (%)		43		47		37		52		25		1		
***p*-value**		0.0003		0.0036		0.0289		0.0015		0.0252		0.2065[a]		

All summary statistics are based on storm averages and not on individual grab samples.

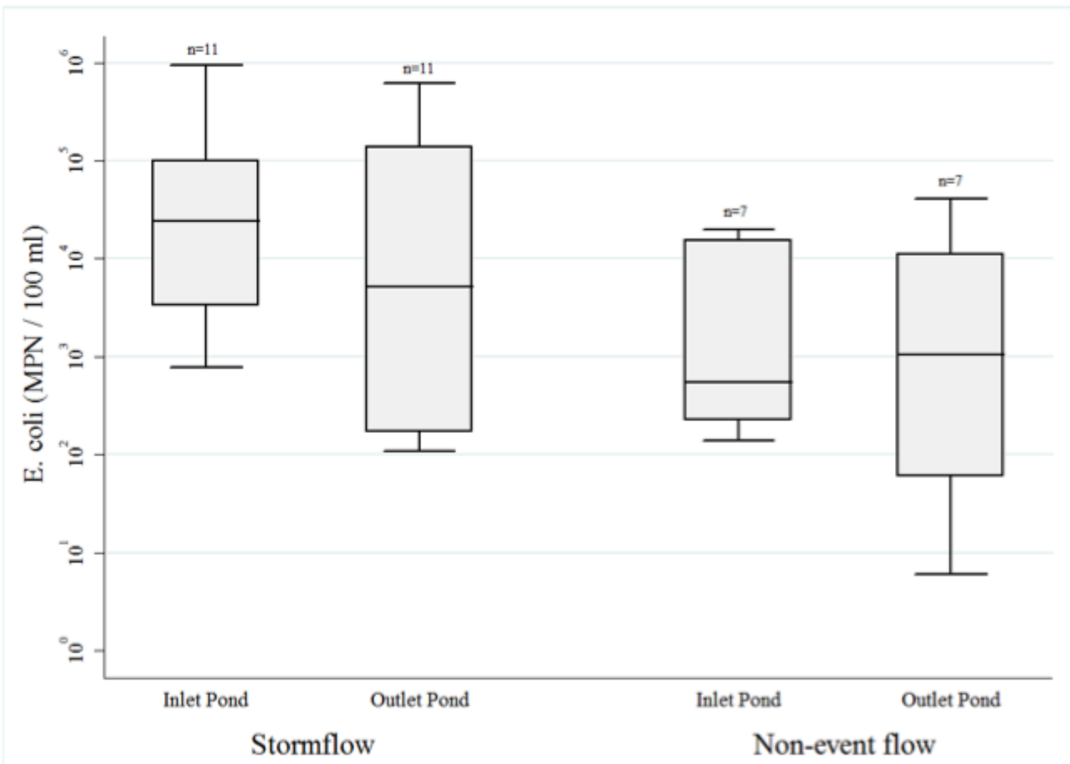
The bimodal storm hydrograph had an earlier peak that was greater in magnitude than the later peak, which occurred several hours later. Storm events on 14 November and 3 December 2009 both resulted in overflow and thus represented high throughput flows through the treatment system. For both storm events, gravel wetland inflows and outflows were comparable despite differences in rainfall amounts, and the duration of gravel wetland inflows was longer than outflows. Gravel wetland outflows on 14 November occurred approximately two hours after inflows began, because the gravel wetland first needed to fill up before there could be flow out. Under wet soil conditions, rainfall increases can translate into a rapid runoff response within the catchment. Flows into and out of the gravel wetland occurred almost simultaneously as a result of the rain event on 3 December 2009. This occurred because the gravel wetland was still flooded from a significant rain event (18.4 mm) four days earlier.

During the study period, seven non-event flows were sampled and were characterized by little or no flow into the gravel wetland. Non-event flows were sampled between one and ten days after storm events.

Storm flow mean outlet pond concentrations were significantly lower ($p < 0.05$) than at the inlet pond for TP, PP, TDP, DRP, and TSS, suggesting that the treatment system reduced pollutant concentrations in agricultural stormwater during the study period. Mean and median concentration reductions between the inlet and outlet pond were generally comparable. However, median concentration reductions were always greater than mean concentration reductions, because phosphorus and TSS distributions tended to be left-skewed for the inlet pond and right-skewed for the outlet pond. TP concentration reductions observed in this study were comparable to mean and median TP reductions (49 and 48%) for twenty-one pond-wetland systems (Kadlec and Wallace, 2008). However, Kadlec and Wallace (2008) reported much higher mean and median TSS concentration reductions for the pond-wetland systems than in this study.



Storm flow outlet *E. coli* concentrations were not significantly lower ($p = 0.2065$) than at the inlet. Inlet and outlet pond *E. coli* concentrations were extremely variable. Inlet and outlet storm flow *E. coli* concentrations both spanned three orders of magnitude and had coefficients of variation that were 2.37 and 1.89, respectively. Storm flow mean and median concentration reductions for *E. coli* were 1 and 78%, respectively.



2. Intensive Sampling of Gravel Wetland

Automatic sampling revealed that for storm events on 14 November and 3 December 2009, the gravel wetland retained, respectively, 130 and 80 g of P and 7.2 and 9.2 kg of TSS, which represented P removal efficiencies of 39 and 13% and TSS removal efficiencies of 42 and 38%. Results for P were generally comparable to those of (Raisin et al., 1997), who reported P removal efficiencies between 0 and 63% for a small storm event driven constructed wetland in an agricultural watershed. The gravel wetland's treatment performance for TSS was also comparable to reported values in the literature. Average outflow TSS concentrations for the first and second storm flows were 28.0 and 40.6 mg L^{-1}, respectively. Kadlec and Wallace

(2008) reported that for twenty-six horizontal subsurface flow wetlands spanning 130 years of system operation, the average effluent TSS concentration was 22.5 mg L^{-1} and that the 90th percentile limit was 42 mg L^{-1}.

Table 4.4. Storm event flow and phosphorus and suspended solids load data for gravel wetland during intensively sampled storms

		Storm Event	
		11/14	12/3
Rainfall	**Amount (mm)**	25.4	15.0
	Duration (h)	13	11
Flow (m^3)	**In**	360	330
	Out	350	310
P Load (g)	**In**	330	600
	Out	200	520
P Retained (g)		130	80
TSS Load (kg)	**In**	17.1	24.2
	Out	9.9	15.0
TSS retained (kg)		7.2	9.2
P Removal Efficiency (%)		39	13
TSS Removal Efficiency (%)		42	38

Results from this study demonstrated that concentrations of TP, PP, TDP, DRP, TSS, and *E. coli* were frequently lower at the stormwater treatment system's outlet than at its inlet. Additionally, intensive sampling during two high throughput storm flows showed that the gravel wetland retained a portion of the P and TSS load from the small dairy barnyardcatchment. Results also seem to suggest that longer inter-event periods may result in lower pollutant loading rates into the gravel wetland and better treatment. Together these results suggest that the recently constructed stormwater treatment system was able to reduce pollutant concentrations during its first five months in operation. However, the results also indicated that treatment performance for *E. coli* was variable and that storm flows resulting in overflow are likely to reduce the overall performance of the treatment system. Observations in the field during the study indicate that minimizing post- construction erosion of treatment structures is likely important for protecting downstream water quality and maintaining proper flows through the treatment system. Because treatment observed during start-up is not representative of long-term performance, the results from this study provide promising evidence that performance will improve as the system re-vegetates and matures

REFERENCES

Cronk J.K. (1996) Constructed wetlands to treat wastewater from dairy and swine operations: A review. Agriculture Ecosystems & Environment 58:97-114.

Eaton A.D., Clesceri L.S., Greenberg A.E. (1998) Standard methods for the examination of water and wastewater. 20th ed. American Public Health Association, Washington, D.C.

Kadlec R.H., Wallace S.D. (2008) Treatment Wetlands. 2nd ed. CRC Press, Boca Raton, FL.

Knight R.L., Payne V.W.E., Borer R.E., Clarke R.A., Pries J.H. (2000) Constructed wetlands for livestock wastewater management. Ecological Engineering 15:41-55.

Raisin G.W., Mitchell D.S., Croome R.L. (1997) The effectiveness of a small constructed wetland in ameliorating diffuse nutrient loadings from an Australian rural catchment. Ecological Engineering 9:19-35.

Rekolainen S., Posch M., Kamari J., Ekholm P. (1991) Evaluation of the accuracy and precision of annual phosphorus load estimates from two agricultural basins in Finland. Journal of Hydrology 128:237-255.

Tanner C.C., Nguyen M.L., Sukias J.P.S. (2005) Nutrient removal by a constructed wetland treating subsurface drainage from grazed dairy pasture. Agriculture Ecosystems & Environment 105:145-162. DOI: 10.1016/j.agee.2004.05.008.

Bishop P.L., Rafferty M.R., Lojpersberger J.L. (2003) Event-based water quality monitoring to determine effectiveness of agricultural BMPs, *In* Proc. of the American Water Resources Association (AWRA) Int. Congress on Watershed Management for Water Supply Systems, AWRA, Middleburg, VA.

Carpenter S.R., Caraco N.F., Correll D.L., Howarth R.W., Sharpley A.N., Smith V.H. (1998) Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8:559-568.

Easton Z.M., Walter M.T., Steenhuis T.S. (2008) Combined monitoring and modeling indicate the most effective agricultural best management practices. Journal of Environmental Quality 37:1798-1809. DOI: 10.2134/jeq2007.0522.

Eaton A.D., Clesceri L.S., Greenberg A.E. (1998) Standard methods for the examination of water and wastewater. 20th ed. American Public Health Association, Washington, D.C.

Gitau M.W., Gburek W.J., Jarrett A.R. (2005) A tool for estimating best management practice effectiveness for phosphorus pollution control. Journal of Soil and Water Conservation 60:1-10.

Hively W.D., Bryant R.B., Fahey T.J. (2005) Phosphorus concentrations in overland flow from diverse locations on a New York dairy farm. Journal of Environmental Quality 34:1224-1233.

Jamieson R., Gordon R., Joy D., Lee H. (2004) Assessing microbial pollution of rural surface waters - a review of current watershed scale modeling approaches. Agricultural Water Management 70:1-17. DOI: 10.1016/j.agwat.2004.05.006.

Jamieson R.C., Gordon R.J., Sharpies K.E., Stratton G.W., Madani A. (2002) Movement and persistence of fecal bacteria in agricultural soils and subsurface drainage water: a review. Canadian Biosystems Engineering 44:1-9.

Jokela W.E., Clausen J.C., Meals D.W., Sharpley A.N. (2004) Effectiveness of agricultural best management practices in reducing phosphorus loading to Lake Champlain, in: T. O. Manley, et al. (Eds.), Lake Champlain: partnerships and research in the new millenium, Kluwer Academic/ Plenum Publishers, New York. pp. 39-52.

LCBP. (2003) Opportunities for Action: An Evolving Plan for the Future of the Lake Champlain Basin, Lake Champlain Basin Program, Grand Isle, VT. pp. 1-144.

LCBP. (2008) State of the Lake and Ecosystem Indicators Report - 2008, Lake Champlain Basin Program, Grand Isle, VT. pp. 1-32.

McDowell R., Sharpley A., Folmar G. (2001) Phosphorus export from an agricultural watershed: linking source and transport mechanisms. Journal of Environmental Quality 30:1587-1595.

Meals D.W. (1989) Bacteriological water quality in Vermont agricultural watersheds undergoing land treatment. Lake and Reservoir Management 5:53-62.

Meals D.W. (1996) Watershed-scale response to agricultural diffuse pollution control programs in Vermont, USA. Water Science and Technology 33:197-204.

Meals D.W. (2001) Lake Champlain Basin agricultural watersheds section 319 national monitoring program project, final project report: May, 1994 - September, 2000, Vermont Dept. of Environmental Conservation, Waterbury, VT. pp. 1-19.

Meals D.W., Budd L.F. (1998) Lake Champlain Basin nonpoint source phosphorus assessment. Journal of the American Water Resources Association 34:251-265.

Michaud A.R., Laurzier R., Laverdiere M.R. (2004) Temporal and spatial variability in non-point source phosphorus in relation to terrestrial indicators: the Beaver Brook case study, Pike River Basin, Quebec, in: T. O. Manley, et al. (Eds.), Lake Champlain: partnerships and research in the new millenium, Kluwer Academic/Plenum Publishers, Boston.

Noll M.R., Magee E.A. (2009) Quantification of phosphorus sources to a small watershed: A case study of Graywood Gully, Conesus Lake, NY. Journal of Great Lakes Research 35:50-55.

Schellinger G.R., Clausen J.C. (1992) Vegetative filter treatment of dairy barnyard runoff in cold regions. Journal of Environmental Quality 21:40-45.

Sharpley A.N., Chapra S.C., Wedepohl R., Sims J.T., Daniel T.C., Reddy K.R. (1994) Managing Agricultural Phosphorus for Protection of Surface Waters - Issues and Options. Journal of Environmental Quality 23:437-451.

Simon R.D., Makarewicz J.C. (2009a) Storm water events in a small agricultural watershed: characterization and evaluation of improvements in stream water microbiology following implementation of best management practices. Journal of Great Lakes Research 35:76-82.

Simon R.D., Makarewicz J.C. (2009b) Impacts of manure management practices on stream microbial loading into Conesus Lake, NY. Journal of Great Lakes Research 35:66-75.

Sims J.T., Kleinman P. (2005) Managing agricultural phosphorus for environmental protection in: J. T. Sims and A. N. Sharpley (Eds.), Phosphorus: Agriculture and the environment, American Society of Agronomy, Madison, WI.

Smeltzer E., Dunlap F., Simoneau M. (2009) Lake Champlain phospohrus concentrations and loading rates, 1990-2008, Lake Champlain Basin Program, Grand Isle, VT. pp. 1-44.

Troy A., Wang D., Capen D. (2007) Updating the Lake Champlain Basin land use data to improve prediction of phosphorus loading. Technical Report No. 54, Lake Champlain Basin Program, Grand Isle, VT. pp. 1-121.

USEPA. (1986) Quality citeria for water, 1986 U.S. Environmental Protection Agency, Washington, DC.

Vermont Agency of Agriculture Food and Markets. (2008) Act 78 - section 16 annual report, 2008, Vermont Agency of Agriculture, Food, and Markets, Montpelier, VT.

Vermont Natural Resources Board. (2008) Vermont water quality standards, Montpelier, VT.